Protecting FSS Earth Stations

CBRS Method of Procedure

Supplement to the Key Bridge Proposal
to Administer a Spectrum Access System

Key Bridge LLC

Jesse Caulfield, CEO

1750 Tysons Blvd., Suite 1500
McLean, VA 22102
Phone: +1 (703) 542-4140
http://keybridgewireless.com

Document Information

Document Status	Public
Version	1.0.0
Date Printed	September 27, 2016
Copyright	

1 Introduction

This document describes a model and method of procedure to implement protection of FSS earth stations in a Spectrum Access System, as required by and described in 47 CFR §96.17. The model calculates aggregate received interference power level at a FSS earth station from a candidate population of CBSDs according to point-to-point link analysis for each CBSD.

Illustration 1: Fixed satellite service earth stations.

A typical fixed-satellite earth station facility is shown in Illustration 1 where various earth station antennae are configured to transmit and / or receive signals with a satellite in geosynchronous orbit.

The model provided in this document will protect FSS earth stations from receiving unwanted interference from CBSDs in the 3,600 – 3,700 MHz (co-channel) band and also in the 3,700 – 4,200 MHz (adjacent) band.

2 Method of Procedure

A SAS protects Fixed Satellite Service (FSS) earth stations in the 3,600 – 3,700 MHz band and the 3,700 – 4,200 MHz band by adjusting CBSD transmit power in a manner consistent with the Commission's rules and implemented according to the following procedure, which implements a standard point-to-point link budget analysis to compute received interference power levels.[1] The procedure includes the following four steps:

1. Identify FSS earth stations to be protected

1 See 47 CFR §96.17 Protection of existing fixed satellite service (FSS) earth stations in the 3600-3700 MHz Band and 3700-4200 MHz Band.

2. Identify candidate CBSDs
3. Calculate specific received interference power level
4. Calculate aggregate received interference power level
5. Implement interference mediation techniques (if required)

2.1 Identify FSS Earth Stations to be Protected

The list of registered FSS earth stations in the 3600-3700 MHz band is available on line at http://www.fcc.gov/cbrs-protected-fss-sites. This includes protected (co-channel) earth stations below 3700 MHz and protected (adjacent band) earth stations in the 3700-4200 MHz Band.

The preliminary list of protected sites (as of September 25, 2016) does not indicate which satellite or geosynchronous orbital position each station services. Without target satellite or orbital position information the SAS will presume that each FSS earth station antenna is configured to operate on a satellite located at the earth stations equivalent longitude (i.e. 180 degrees South azimuth for North American stations) and at the calculated elevation angle for the station's respective latitude.

2.2 Identify Candidate CBSDs

Candidate CBSDs that may require SAS intervention include, for the 3600 – 3700 MHz band and as measured from the FSS earth station position:[2]

- all co-channel CBSDs operating within a 150 km radius; and
- all in-band but not co-channel (i.e. adjacent) CBSDs operating within a 40 km radius.

Candidate CBSDs that may require SAS intervention include, for the 3700 – 4200 MHz band and as measured from the FSS earth station position:

- all CBSDs operating within a 40 km radius.

2.3 Calculate Specific Received Interference Power Level

The FSS received interference power level I^{FSS}, in dBW, from a specific candidate CBSD within a FSS earth station receiver passband is calculated as:

$$I^{FSS} = 10\log(P_T) + G_T - L_{CT} + G_R + L_{CR} - L_P - L_T - L_{POL} - FDR \qquad (2\text{-}1)$$

2 See Report and Order, *In the Matter of Wireless Operations in the 3650-3700 MHz Band* ET Docket No. 04-151 FCC 05-56 (March 16, 2005) (*3650 Order*) at 65. To further assure that FSS earth stations are adequately protected, we will impose the protection distance as a circular zone around the earth station. [In] practice, each earth station can look at multiple satellites across the geostationary arc. Thus, a circular protection zone is more appropriate for ensuring interference protection in all cases. In addition, we point out that using a circular zone has the benefit of simplicity for all parties as it is easy to determine exactly which areas are excluded from terrestrial station operation.

where:

I^{FSS} is the received interference power at the input of the FSS antenna (dBW);

P_T is the CBSD transmitter power (dBm)

G_T is the CBSD antenna gain in the direction of the receiving antenna (dBi)

L_{CT} is the cable / insertion loss of the CBSD (dB)

G_R is the FSS receiver antenna gain in the direction of the CBSD source antenna (dBi)

L_{CR} is the cable / insertion loss of the FSS (dB)

L_P is the propagation path loss (dB)

L_T is building and other non-specific terrain loss (dB)

L_{POL} is the antenna polarization mismatch loss (dB)

FDR is the frequency dependent rejection, in dB

The model includes a combination of propagation loss and building/terrain losses for each I^{FSS} computation. This is done to account for variances in CBSD indoor / outdoor installation configurations.

2.4 Calculate Aggregate Received Interference Power Level

The model calculates the received interference signal level using Equation 2-1 for each CBSD device in the candidate distribution. The aggregate received interference power level I_A, in dBW, from the distributed candidate CBSD collection is calculated as:

$$I^{AGG} = \sum_{n \in N} I_n \qquad (2\text{-}2)$$

where:

I^{AGG} is the aggregate interference to the FSS from the CBSDs (dBW);

N is the total number of candidate CBSDs

n is the specific candidate CBSD index reference identifier

I_n is the specific candidate CBSD received interference power level (dBW)

2.5 Implement Interference Mediation Techniques (If Required)

Interference mediation techniques are implemented by the CBSD controlling / responsible SAS.

If any specific received interference power level calculated from Step 2 above is above the thresholds identified in 47 CFR §96.17 then the immediate CBSD will be instructed to reduce its transmission to an acceptable level, to change its operating channel, or to cease operation.

If the calculated aggregate received interference power level is above the thresholds identified in 96.17 then a aggregate CBSD power reduction technique will be effected.

Presently the Key Bridge SAS will implement the following iterative procedure to identify and reduce transmit power of the most interfering CBSDs. The procedure is repeated until the FSS earth station aggregate received interference power level is below the required threshold. After executing each step the aggregate received interference power level is recalculated.

1. Calculate a normalized distribution of received interference power level at the FSS earth station for each candidate CBSD
2. Reduce the transmit power by 0.5 dB for the top 5% of CBSDs in the normalized distribution
3. Repeat at Step 1 until the aggregate received interference power level is acceptable.

Other aggregate power reduction methods that include sophisticated ranking and fairness algorithms may be developed in the future by a multi-stakeholder body and/or recommended by the Commission. The Key Bridge SAS can readily accommodate other Interference Mediation Techniques, and Key Bridge will implement these techniques as appropriate.

3 Discussion

3.1 Antenna Coupling (G_T + G_R)

Antenna coupling between a potentially interfering CBSD and a potential victim FSS receiver is computed using the main bean gains and azimuth orientations of the two antennas.

The antenna gain values G_T and G_R are determined from their respective antenna gain patterns. The gain patterns for the model as currently implemented are considered to be symmetrical relative to boresight (center of mainbeam) in both the elevation and azimuth plane, according to the respective elevation and azimuth patterns. For example, the antenna gain would be the same for *Y* degrees above or below boresight, and the same for *X* degrees in either the clockwise or counter clockwise direction from boresight.

For a given boresight direction of the FSS antenna, the model determines the bearing to the CBSD from the coordinates (azimuth angle) of the FSS and CBSD locations. The model determines the relative elevation angle from the difference in the CBSD and FSS antenna heights above ground and the distance between the antennas. These azimuth and elevation angles are then used with the antenna pattern data to determine the appropriate values for G_T and G_R for each CBSD to FSS earth station path.

3.1.1 CBSD Antenna Gain (G_T)

The CBSD azimuth and elevation antenna pattern models are defined in terms of the antenna gain in decibels relative to an isotropic antenna (dBi) as a function of the azimuth and elevation angles in degrees. The antenna patterns should be obtained from manufacturer data (preferred), from ITU-R recommendations, or provided by each respective CBSD according to its professional installation configuration.[3]

3.1.2 FSS Earth Station Antenna Gain (G_R)

47 CFR §25.209 describes a statistical model representing the envelope of the gain of typical directional FSS earth station antenna in the tangential (azimuth) and perpendicular (elevation) orientations to the geosynchronous satellite orbit (GSO) arc.

The model gives the antenna gain G_R as a function of azimuth and elevation off-axis angle in degrees. Illustration 2 shows the form of the antenna gain distributions as specified in 47 CFR §25.209(a)(1) and (4).

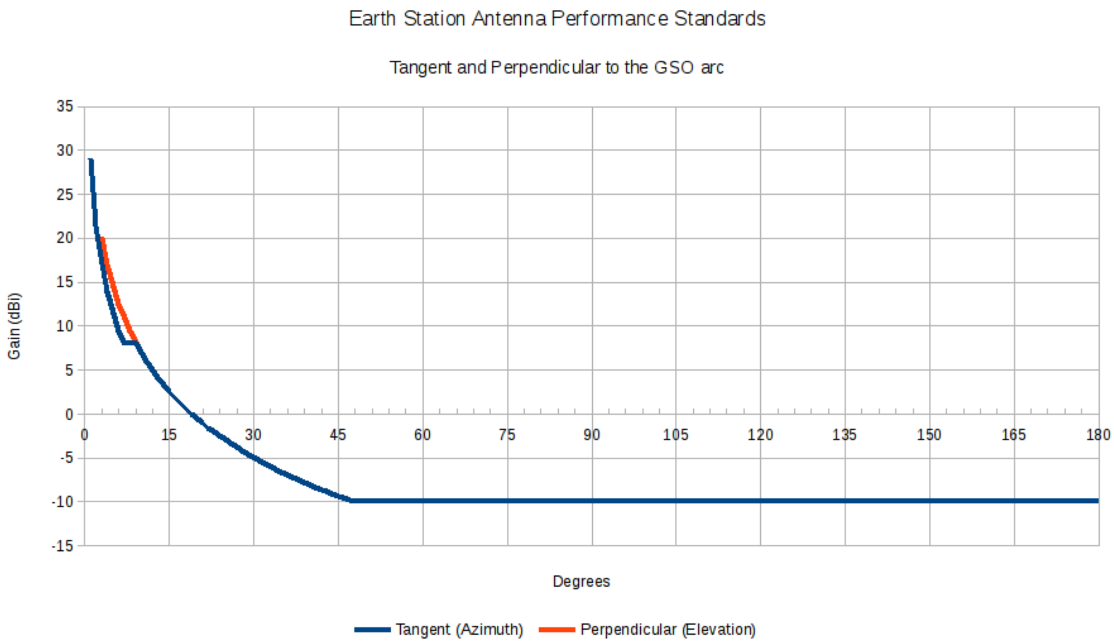

Illustration 2: §25.209(a), (f) Earth station antenna performance standards.

The maximum allowable antenna gain, as a function of off-axis angle in the plane tangent (i.e. azimuthal) to the GSO, is defined as:[4]

3 See International Telecommunication Union, Recommendation ITU-R F.1336-4, *Reference Radiation Patterns of Omnidirectional and Other Antennas in Point-to-Multipoint Systems for Use in Sharing Studies* (2014) (available through agency at https://www.itu.int).

Angular Interval (degrees)	**Gain (dBi)**
$1.5° \leq \theta \leq 7°$	$25-25\log_{10}\theta$
$7° < \theta \leq 9.2°$	8
$9.2° < \theta \leq 48°$	$32-25\log_{10}\theta$
$48° < \theta \leq 180°$	-10

Outside the main beam the maximum allowable antenna gain, as a function of off-axis angle in the plane perpendicular (i.e. elevational) to the GSO, is defined as:[5]

Angular Interval (degrees)	**Gain (dBi)**
$3° \leq \Phi \leq 48°$	$32-25\log_{10}\Phi$
$48° < \Phi \leq 180°$	-10

On-axis main beam gain values less than 1.5 degree tangential or 3 degree perpendicular to the GSO arc are specific to each earth-station antenna.

3.1.2.1 Earth station elevation angle (Φ)

Satellites in geostationary orbits remain above a fixed location on the earth's equator at a constant geocentric distance. Since the satellite's position is expressed with respect to a geocentric coordinate system that rotates with the earth, the earth station's position is time–invariant and is calculated only once. The earth station's position is calculated in terms of radial distance from the rotational axis of the earth and axial distance north of the equatorial plane of the earth.

Geometric algorithms to calculate earth station pointing configurations are well established.[6] The model uses Appendix D of FCC Report and Order permitting Wireless Operations in the 3650-3700 MHz Band, which itself is a summary of known methods.[7] Appendix D consolidates other first-principal derivations and provides a formula to determine the elevation angle of an earth station as:

$$\Phi^{FSS}=\arctan\left[\frac{\cos(\Delta)\cos(L_e)-0.1512}{\sqrt{1-\cos^2(\Delta)\cos^2(L_e)}}\right] \quad , \quad \Delta=S-N$$

where:

4 See 47 CFR §25.209 at (a)(1)- Earth station antenna performance standards. The allowable antenna gain as a function of off-axis angle is calculated with zero degrees set to the antenna boresight.

5 Ibid at (a)(4).

6 See, for example, Intelsat Earth Station Standards, *Earth Station Pointing Data* IESS-412 (2002), and National Geodetic Survey, *Determination of Look Angles to Geostationary Communication Satellites* (1995) (available through respective agencies)

7 See 3650 Order, Appendix D: *A Methodology For Locating Fixed Stations Within The FSS Earth Station Protection Zone*

Φ^{FSS} is the earth station elevation angle (degrees)

L_e is the earth station latitude (degrees)

Δ is the longitudinal distance between the satellite and earth station (degrees)

S is the satellite longitude (degrees)

N is the earth station longitude (degrees)

3.2 Radiowave Propagation Loss (L_P)

The model supports three similar options to compute the radiowave propagation loss, with selection based upon the preference of the implementor. These are, in order of preference:

1. ITU Recommendation P.2001-2
2. ITU Recommendation P.452-16
3. Irregular Terrain Model (ITM) (Longley-Rice)

The first (preferred) option is ITU-R P.2001-2, a general purpose, wide-range model for terrestrial propagation that predicts path loss due to both signal enhancements and fading. The model covers the frequency range from 30 MHz to 50 GHz, and distances from 3 km to at least 1 000 km.[8] P.2001-2 is a generalization of the path loss methodologies described in the P452-16 and ITM models.

The second option is ITU-R P.452-16, a prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz range 30 MHz to 50 GHz and accounting for both clear-air and hydrometeor scattering interference mechanisms.[9]

The third option is ITM / Longley-Rice, a general purpose model based on electromagnetic theory and on statistical analyses of both terrain features and radio measurements for frequencies between 20 MHz and 20 GHz.[10]

The Key Bridge SAS will implement and use the ITU Recommendation P.2001-2 model for radiowave propagation loss.

---

8 See *P.2001 : A general purpose wide-range terrestrial propagation model in the frequency range 30 MHz to 50 GHz* (2015) (available through agency at https://www.itu.int)

9 See *P.452 : Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz* (2015) (available through agency at https://www.itu.int)

10 See Technical Note TN-101 vol. I Transmission Loss Predictions for Tropospheric Communication Circuits: Volume I (Publication #2726) and Volume II (Publications 2727) (1967) (available through agency at http://www.its.bldrdoc.gov). The original reports are referenced here instead of their later software implementations as the software includes various engineering shortcuts and empirical constants.

3.3 Frequency Dependent Rejection

Frequency Dependent Rejection (FDR) is a measure of the rejection produced by the receiver selectivity curve on an unwanted transmitter emission spectra. FDR accounts for the fact that not all of the undesired transmitter energy at the receiver input will be available at the detector, and is a calculation of the amount of undesired transmitter energy that is rejected by a victim receiver. A detailed description of how to compute FDR can be found in ITU Recommendation SM.337-6.[11]

3.4 Data Availability in the ULS Database

The list of registered FSS earth stations in the 3600-3700 MHz band is available on line at http://www.fcc.gov/cbrs-protected-fss-sites.[12] The preliminary list of protected sites (as of September 25, 2016) does not indicate a satellite or satellite orbital position for each registered FSS earth station.

- Issue: Antenna azimuth configuration is missing

Without a satellite or geosynchronous orbital position (or further guidance from the Commission), the Key Bridge SAS will calculate protections for each FSS earth station antenna as operating on a satellite located at the earth stations equivalent longitude (i.e. 180 degrees South azimuth for North American stations) and at the calculated elevation angle for the station’s respective latitude.

11 See See International Telecommunication Union, Recommendation SM.337-6, *Frequency and distance separations* (available through agency at https://www.itu.int).

12 The URL http://www.fcc.gov/cbrs-protected-fss-sites is specified in 47 CFR §96.17(a) and (b).

Attachments

- 04-151 Appendix D: A Methodology For Locating Fixed Stations Within The FSS Earth Station Protection Zone
- 04-151 Appendix E: List Of Grandfathered FSS Earth Stations (informational)
- 04-151 Appendix F: Protection Zones For Grandfathered FSS And Federal Government Stations (informational)

APPENDIX D: A Methodology For Locating Fixed Stations Within The FSS Earth Station Protection Zone

The rules adopted herein require that fixed stations in the 3650-3700 MHz band be located at least 150 km from any grandfathered FSS earth station unless all affected licensees agree on closer spacing. Below, we present as an example, one methodology that can be used to determine a safe distance within the FSS earth station protection zone where a fixed station can be located without increasing the potential of that station to cause harmful interference to the earth station. We reiterate that this is being presented only as an example of one methodology. We recognize that there are many methods for providing the required protection, such as locating the fixed station behind an obstruction, and that licensees are free to propose any method they deem appropriate.

The 150 km protection zone is based on an analysis of the interference potential of a fixed station to a victim earth station under worst case operating conditions.[186] The methodology presented below recognizes that in most cases, the earth station does not operate in its worst case configuration. Using this fact, fixed stations can take advantage of the isolation provided by the higher elevation angles with which earth stations generally operate and transmit from locations within the protection zone without causing interference. This computed separation distance is based on the maximum level of interference noise power that may be caused to an FSS earth station.[187]

The Tables below show the assumptions and parameters used in our analysis:[188]

[186] As pointed out above, FSS earth stations must be protected for use of the full geostationary satellite arc. Thus, the worst case operating conditions are for a satellite operating at the extreme east or west edge of the arc with a 5^{o} elevation angle.

[187] The methodology presented herein does not assume any discrimination due to the pointing of the fixed station antenna (*e.g.*, the fixed station could be pointed directly away from the earth station). Thus, for fixed stations that use directional antennas better results than those calculated here can be achieved.

188 The maximum level of interference noise power caused to an FSS earth station is based on the earth station antenna gain at an off-axis angle θ (degrees) referred to the main beam axis. This is measured from the axis of the main beam of the earth station.

Table 1: Typical FSS Earth station parameters

Earth Stations	3650-3700 MHz					
Antenna reference pattern[189]	47 CFR §25.209 (a)(2)					
Off-axis gain towards the local horizon (dBi)[190,]	Elev. Angle	5°	15°	25°	35°	≥48°
	Off-axis gain	14.5	2.6	–2.9	–6.6	–10.0
Receive Bandwidth (range)	40 kHz-36 MHz					
Receive center frequency	3675 MHz					
Polarization	Linear or circular					
Earth station system noise temperature[191]	142.8^o K					
Deployment	All regions, in all locations (rural, suburban, urban)[192]					

Table 2: Fixed station parameters

Fixed stations	Parameters
Maximum transmit EIRP density	25 watts/25 MHz
Antenna type	Omni or directional

As mentioned, the methodology presented here takes advantage of the fact that earth stations are generally not operating in the worst case configuration. More specifically, we recognize that the elevation angle of an earth station varies in relationship to the position of the geostationary satellite with which it communicates.[193] Further, the range of pointing azimuths[194] and elevation angles that an earth station uses varies with its location – as earth stations are located at higher latitudes, the size of the visible

189 *See* recommendation ITU-R S.465. See also http://ntiacsd.ntia.doc.gov/ussg1/temp/TG1-8/052e+plen.doc.

The antenna radiation pattern in the plane of the horizon set forth in Section 25.209(a)(2) of our rules for earth stations pointing towards the geostationary arc is:

32-25*log10 (θ) dBi, for $1 \leq \theta < 48°$.

-10 dBi, for $48° \leq \theta \leq 180°$.

190 The values were derived by assuming a local horizon at 0° of elevation. Note that the off-axis antenna gain is independent of the earth station antenna diameter.

191 See SIA comments at 3 of Exhibit 1. The maximum interference permitted at the earth station receiver input is measured in terms of an increase to the earth station noise floor. An interference criterion typically used to quantify the amount of interference that can be tolerated by a satellite system or an earth station is known as the ΔT/T threshold. This criterion is related to the increase in system noise temperature and corresponds to the interference-to-noise ratio, I/N, (*i.e.,* 10 log (ΔT/T)).

192 FSS ES antennas in this band may be deployed in a variety of environments: smaller antennas (*e.g.,* 1.8m -3.8m) are commonly deployed on the roofs of buildings in urban or semi-urban locations , whereas larger antennas (4.5m and above) are typically mounted on the ground and deployed in semi-urban or rural locations.

193 All geostationary satellites are located approximately 36,000 km above the equator at 0^o latitude.

194 Azimuth is measured by using true north as the reference point. Thus an azimuth of north is 0^o, east is 90^o, south is 180^o, and west is 270^o.

geostationary arc decreases limiting the available azimuth angles and the elevation angles necessary to see these satellites gets lower.[195]

In the next sections, we will show how to calculate the minimum separation distance between a single fixed station and a single FSS earth station. Finally, we provide an example calculation of the minimum separation required separation distance of a fixed station from several FSS earth stations.

Section 1: Determine the MINIMUM separation distance between a single fixed station and a single FSS Earth station.

Several steps are necessary to determine the minimum separation distance between a fixed station and an FSS earth station. To make this calculation, the first step is to determine the location of the eastern and western limits of the visible geostationary arc for any given the fixed station location. Then, a calculation can be made to determine the discrimination angle (*i.e.,* off-axis angle) between the axis of the main beam of the earth station and the fixed station. Using this value, the earth station antenna gain in the direction of the fixed station can then be calculated. Finally, the minimum distance can be calculated.

Step 1: Determine the eastern and western limits of the visible geostationary arc for any FSS earth station. As previously stated, this corresponds to an earth station with a 5^o elevation angle

The elevation angle of an earth station can be calculated using the following formula: [196]

$$El = \arctan\left[\frac{\cos(\Delta) * \cos(Le) - 0.1512}{\sqrt{1-\cos^2(\Delta) * \cos^2(Le)}}\right]$$ Equation 1[197]

Where:

El = Earth station elevation angle in degrees

Le= Earth station latitude in degrees

Δ =S-N

and

S = Satellite longitude in degrees

N= Earth station longitude in degrees

Rearranging Equation 1, yields:

$$\cos^2(\Delta)\cos^2(Le)(1+\tan^2(El)) - 2(0.1512)\cos(\Delta)\cos(Le) + (0.1512)^2 - \tan^2(El) = 0;$$ Equation 2

[195] For example, a typical earth station located at 25^o north latitude has range of elevation angles between 5^o and 66^o. In contrast, an earth station located at 76.3^o north latitude can only see one satellite at a maximum elevation angle of 5 degrees, corresponding to 180 azimuth.

[196] The equations used in this analysis assume North latitude and West longitude.

[197] Douglas, Robert L. "Satellite Communications Technology". Prentice Hall Publishers. Englewood Cliffs, NJ, 1988, pg 89.

If we let $X = \cos(\Delta)\cos(Le)$, then

$$S = \arccos\left(\frac{X}{\cos(Le)}\right) + N$$

Where:

S = the westernmost satellite longitude visible to an earth station operating at 5^o elevation angle.

Then Equation 2 simplifies to a quadratic equation:

$a*X^2 + b*X + c = 0$[198] Equation 3

Where:

$a = (1+\tan^2 (El))$;

$b = - 2(0.1512)$;

$c = (0.1512)^2 - \tan^2 (El)$

The practical root, X_1, of equation 3 can then be used to determine the deviation from the earth station longitude that defines the eastern and western limits of the visible geostationary arc.

If we let $W = \arccos\left(\frac{X_1}{\cos(Le)}\right)$

Where W = deviation from earth station longitude that defines visible geostationary arc

Then the visible geostationary arc is:

$(N - W) \leq$ visible Arc $\leq (N + W)$

Where: $(N - W)$ and $(N + W)$ are the easternmost and westernmost satellite longitudes visible to an earth station operating at 5^o elevation angle.

[198] This is solved using the quadratic formula to yield two roots X_1 and X_2

$X_1 = (-b + \mathrm{sqrt}(b^2 - 4ac))/2a$;

$X_2 = (-b - \mathrm{sqrt}(b^2 - 4ac))/2a$; this root is rejected because it provides a solution for a negative elevation angle.

This result can be converted from degrees longitude to a corresponding azimuth angle from true North. These azimuth angles are used in the steps that follow.[199]

$$Azimuth = 180 + \arctan\left[\frac{\tan(\Delta)}{\sin(Le)}\right]$$

Thus, the visible geostationary arc is:

$$180 + \arctan\left[\frac{\tan(-W)}{\sin(Le)}\right] \leq \text{Visible Arc} \leq 180 + \arctan\left[\frac{\tan(W)}{\sin(Le)}\right]$$

Step 2: Determine the angle between the axis of the main beam of the earth station and the fixed station (*i.e.,* off-axis angle, θx). This angle is calculated using the formula:[200]

$$\theta x = \arccos(\cos(El) * \cos(As - Af)) \qquad \text{Equation 4}^{201}$$

Where:

θx: off-axis angle[202];
El: Earth station elevation angle
As: Azimuth from earth station towards the satellite
Af: Azimuth from earth station towards the fixed station

Step 3: Determine the earth station antenna gain that corresponds to the value of θx.

$$Gd = 32 - 25 * \log(\theta x) \qquad \text{Equation 5}$$

Where:

Gd = earth station antenna gain in the direction of the fixed station

[199] Douglas, Robert L. "Satellite Communications Technology". Prentice Hall Publishers. Englewood Cliffs, NJ, 1988, pg. 91.

[200] The earth station antenna discrimination angle between the its pointing vector (*i.e.*, direction towards a satellite) and its local horizon in the direction of the fixed facility can be determined using vector dot products and spherical geometry. Dot product is defined by the equation: Dot(A, B) = ||A||*||B||*cos(θx). For the smooth earth case, the relationship reduces to cos(θx) = cos(EL)*cos(As – Af).

[201] The 150 km protection zone is based on a worst case scenario. This occurs when the axis of the main beam of the fixed station points directly towards the axis of the main beam of the earth station. In this scenario, As = Af and the off axis angle θx becomes equal to the earth station elevation angle, El. We note that in order for this worst case to occur, two independent stations would need to be perfectly aligned. Therefore, we believe the likelihood of this occurring to be very small.

[202] This is often referred to as the discrimination angle.

Step 4: Calculate the minimum separation distance required between the earth station and the fixed station based on the fixed station location and the earth station antenna gain in the direction of the fixed station.

$$Mfx = 18.17 * Exp^{(-0.055 * Gd)}$$ Equation 6

Where:
Mfx = variable accounting for all propagation losses other than free space (*e.g.*, multipath, etc.)[203]

Finally,

$$Dx\ (km) = \frac{150}{10^{\left[\frac{(-0.724 + Gd - Mfx)}{20}\right]}}$$ Equation 7

Where:
Dx = minimum separation distance in kilometers

Section 2: Example Calculation OF MINIMUM SEPARATION DISTANCE BETWEEN A FIXED STATION AND MULTIPLE EARTH STATIONS

This example assumes a fixed station located within 150 km of four earth stations.[204] The fixed station has an omnidirectional antenna and is located at 37^o north latitude and 80^o west longitude. It is assumed that the earth stations are located at the following coordinates.

Earth Station1: 38^o North latitude; 80^o west longitude - 111.20 km from fixed station

Earth Station2: 37^o North latitude; 81^o west longitude - 88.80 km from fixed station

Earth Station3: 36^o North latitude; 80^o west longitude - 111.20 km from fixed station

Earth Station4: 37.15^o North latitude; 81^o west longitude - 90.27 km from fixed station

[203] This term was created as a simplification of all the factors that account for propagation loss. It is a conservative estimation of loss based solely on the off axis discrimination angle (*i.e.*, the lower the elevation angle the greater the loss). This equation yields results consistent with the propagation model used by SIA in the analysis submitted in their comments.

[204] The great circle distance, D, between two points with coordinates {lat1, lon1} and {lat2, lon2} is given by:

D (km) = 6371* arccos(sin(lat1)*sin(lat2)+cos(lat1)*cos(lat2)*cos(lon1-lon2))

Using the approach described above, the full arc in azimuth for each earth station is:

Earth Station1: $100.95^o \leq$ Full Arc $\leq 259.05^o$

Earth Station2: $100.56^o \leq$ Full Arc $\leq 259.44^o$

Earth Station3: $100.17^o \leq$ Full Arc $\leq 259.83^o$

Earth Station4: $100.61^o \leq$ Full Arc $\leq 259.39^o$

The azimuth angle from each earth station to the fixed station can be computed:[205]

Earth Station1 Azimuth = 180 degrees;

Earth Station2 Azimuth = 90 degrees;

Earth Station3 Azimuth = 0 degrees.

Earth Station4 Azimuth = 100.35 degrees.

Now, the earth station off-axis angle can be calculated using equation 4:

Earth Station1 θx = arcos (cos(5)*cos(180-100.95)) = 79.09 degrees.

Earth Station2 θx = 11.67 degrees

Earth Station3 θx = 100.13 degrees

Earth Station4 θx = 5.0 degrees

Using the off axis angle, the antenna gain towards the fixed station is given by equation 5.

Earth Station1 Gd = -10 dBi

Earth Station2 Gd = 5.32 dBi

Earth Station3 Gd = -10 dBi

Earth Station4 Gd = 14.53 dBi

[205] Except for earth station4, the azimuth angles can be determined by inspection. In general, the following equations can be used to determine azimuth angle between two points:

phi = arcos((sin(lat2) - sin(lat1)*cos(D)) / (sin(D)*cos(lat1))); where D is the great circle distance between the two points under consideration

IF sin(lon2-lon1) < 0, Az = phi

IF sin(lon2-lon1) > 0, Az = 2*pi – phi

Note: these equations do not work if one point is located at the north or South Pole.

The corresponding separation distances can be determined by equations 6 and 7:

Required separation distance to Earth Station1, D1 = 37.45 km

Required separation distance to Earth Station2, D2 = 84.56 km

Required separation distance to Earth Station3, D3 = 37.45 km

Required separation distance to Earth Station4, D4 = 150 km

Finally, the required separation distance must be compared to the actual separation distance to ensure adequate protection of the earth station:

Earth Station1, D1 = 37.45 km < 111.20 km

Earth Station2, D2 = 84.56 km < 88.80 km

Earth Station3, D3 = 37.45 km < 111.20 km

Earth Station4, D4 = 150 km > 90.27 km

Therefore, the fixed station is sufficiently far from Earth Stations 1, 2, and 3 to provide interference protection. However, unless an agreement is negotiated, it cannot be located at its proposed location because it is not at a sufficient distance from Earth Station4 to provide the required interference protection.

Calculate the PROTECTION zone around an earth station

Using the methodology presented in this Appendix, a protection zone for an earth station smaller than the 150 km circle adopted in our rules can be calculated. To compute this protection zone, the equations of Section 1 can be solved iteratively for incremental values ranging from 0 to 360 degrees of the fixed station azimuth angle (Af). The figure shown below is an example of the calculated protection zone around an earth station located at 49° north latitude and 120° west longitude.[206] It is important to note that the earth station location used for this example is in the northern part of the U.S.[207] For more southern locations, the minimum separation distance at azimuths directly in front and back of the earth station would be smaller.

[206] The computed visible geostationary satellite arc ranges from -51.1° east longitude to 188.89° west longitude.

[207] This location was chosen for illustrative purposes only and does not imply that there is a grandfathered earth station at this location.

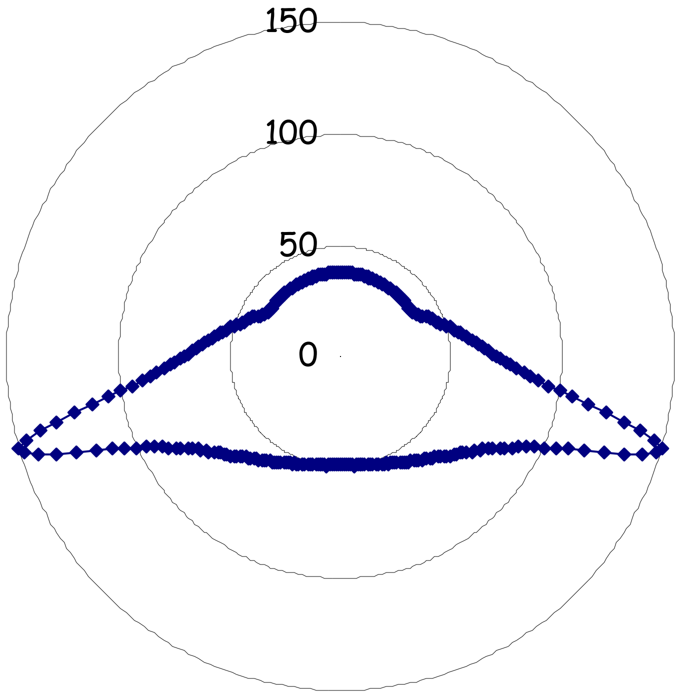

Figure: Earth Station Protection Zone

APPENDIX E: List Of Grandfathered FSS Earth Stations

State	City	Latitude	Longitude	NAD*	Call Sign	Filenumber	Licensee
CA	Chatsworth	34°14'20.70"N	118°34'11.50"W	83	E000326	SESMOD2000112902256	McKibben Communications
CA	Livermore	37°45'40.00"N	121°47'53.00"W	n/s	KA232	SESLIC1997103001576	Sprint Communications Company, L.P.
CA	Malibu	34°4'52.60"N	118°53'52.90"W	83	E980066	SESMOD2000112902218	AT&T Corp.
CA	Malibu	34°4'50.30"N	118°53'46.40"W	n/s	KA273	SESRWL2000072401194	AT&T Corp.
CA	Malibu	34°4'49.70"N	118°53'43.90"W	27	KA91	SESMOD1998081701067	AT&T Corp.
CA	Malibu	34°4'51.00"N	118°53'44.00"W	27	KB32	SESMOD1998081701066	AT&T Corp.
CA	Mountain House	37°45'0.70"N	121°35'37.80"W	83	KA206	SESMOD2000022200272	Pacific Satellite Connection, Inc.
CA	Mountain House	37°45'1.70"N	121°35'38.80"W	83	KA86	SESMOD2000022200265	Pacific Satellite Connection, Inc.
CA	Salt Creek	38°56'20.20"N	122°8'48.00"W	n/s	KA371	SESRWL1999101201864	AT&T Corp.
CA	Salt Creek	38°56'21.00"N	122°8'49.20"W	27	KA372	SESRWL2003103101527	AT&T Corp.
CA	Salt Creek	38°56'22.30"N	122°8'49.60"W	n/s	KA373	SESRWL2000121502350	AT&T Corp.
CA	San Ramon	37°45'39.70"N	121°47'56.80"W	83	E6241	SESMOD2000112902270	Sprint Communications Company L.P.
CA	Somis	34°19'31.00"N	118°59'41.00"W	27	KA318	SESRWL2002030500275	SES Americom, Inc.
CA	Sylmar	34°18'55.00"N	118°29'12.00"W	83	E6148	SESRWL2004102901607	FiberSat Global Services, LLC
CA	Sylmar	34°19'4.00"N	118°29'0.00"W	27	KA274	SESRWL1999022500279	Globecast North America Incorporated
CA	Three Peaks	38°8'51.90"N	122°47'38.00"W	83	E950208	SESMOD2001032600656	Loral Spacecom Corporation
FL	Medley	25°51'19.00"N	80°19'52.00"W	n/s	E960068	SESLIC1995120700087	Teleport Of The Americas, Inc.
FL	Medley	25°50'26.00"N	80°19'3.00"W	27	E960406	SESMOD1999042201041	Globecast North America Incorporated
FL	Melbourne	28°5'10.00"N	80°38'10.00"W	n/s	E950276	SESMOD2003051500668	Harris Corporation
FL	Melbourne	28°2'25.00"N	80°35'48.00"W	27	KA354	SESLIC1995032300008	Melbourne International Communications Limited
FL	Miami	25°55'33.30"N	80°13'16.20"W	83	E980299	SESMOD2000072101188	USA Teleport, Inc.
FL	Miami	25°48'35.00"N	80°21'10.00"W	83	KA407	SESRWL2004030500317	Americasky Corporation
FL	Miami	25°48'35.00"N	80°21'11.00"W	n/s	KA412	SESRWL2004042200574	Americasky Corporation
FL	Miramar	25°58'32.00"N	80°17'0.00"W	n/s	E960105	SESLIC1995122600010	GEMS International Television
FL	Orlando	28°25'29.00"N	81°7'21.00"W	27	KA280	SESRWL2000101902129	Sprint Communications Company L.P.
GU	Pulantat	13°25'0.00"N	144°44'57.00"E	n/s	KA28	SESLIC1997081401122	MCI WORLDCOM Network Services, Inc.
GU	Pulantat	13°25'5.20"N	144°45'5.70"E	83	KA326	SESMOD2000120102250	MCI WORLDCOM Network Services, Inc.
HI	Haleiwa	21°40'14.60"N	158°2'3.10"W	83	KA25	SESMOD2003051300642	Intelsat LLC
HI	Paumalu	21°40'27.00"N	158°2'16.00"W	27	KA265	SESMOD2002040500579	Intelsat LLC
HI	Paumalu	21°40'15.50"N	158°2'6.10"W	83	KA266	SESMOD2004081801190	Intelsat LLC

State	City	Latitude	Longitude	NAD*	Call Sign	Filenumber	Licensee
HI	Paumalu	21°40'14.10"N	158°2'6.10"W	83	KA267	SESMOD2004081801191	Intelsat LLC
HI	Paumalu	21°40'25.00"N	158°2'16.00"W	27	KA268	SESMOD2002040500583	Intelsat LLC
HI	Paumalu	21°40'24.00"N	158°2'16.00"W	27	KA269	SESMOD2004042900611	Intelsat LLC
HI	Paumalu	21°40'24.00"N	158°2'16.00"W	27	KA270	SESMOD2004011300031	Intelsat LLC
MD	Clarksburg	39°13'5.60"N	77°16'12.40"W	27	KA259	SESMOD2002040500569	Intelsat LLC
MD	Clarksburg	39°13'5.00"N	77°16'12.00"W	27	KA260	SESMOD2002040500571	Intelsat LLC
MD	Clarksburg	39°13'2.60"N	77°16'10.90"W	83	KA261	SESMOD2003040200453	Intelsat LLC
MD	Clarksburg	39°13'1.80"N	77°16'11.40"W	83	KA262	SESMOD2003040200454	Intelsat LLC
MD	Clarksburg	39°13'4.40"N	77°16'13.90"W	83	KA263	SESMOD2004040800539	Intelsat LLC
MD	Clarksburg	39°13'5.20"N	77°16'13.90"W	83	KA264	SESMOD2004040800538	Intelsat LLC
MD	Clarksburg	39°13'7.00"N	77°16'12.00"W	83	KA275	SESMOD2003051300641	Intelsat LLC
ME	Andover	44°38'1.20"N	70°41'51.30"W	83	E000306	SESLIC2000062201004	MCI WORLDCOM Network Services, Inc.
ME	Andover	44°38'1.20"N	70°41'51.30"W	83	E000700	SESLIC2000113002229	MCI WORLDCOM Network Services, Inc.
ME	Andover	44°37'58.00"N	70°41'54.00"W	n/s	KA349	SESMOD1997060300716	MCI WORLDCOM Network Services, Inc.
ME	Andover	44°37'58.20"N	70°41'55.30"W	83	KA386	SESRWL2003102101443	MCI WORLDCOM Network Services, Inc.
ME	Andover	44°38'0.00"N	70°41'55.00"W	27	WA20	SESRWL2003091701297	MCI WORLDCOM Network Services, Inc.
ME	Andover #6	44°37'58.20"N	70°41'55.30"W	83	E930190	SESRWL2003062400894	MCI WORLDCOM Network Services, Inc.
NC	West Jefferson	36°25'50.00"N	81°23'45.00"W	n/s	E970334	SESLIC1997052700684	Infotel International Services, Inc.
NJ	Carpentersville	40°38'39.00"N	75°11'29.00"W	27	E7541	SESMOD2000113002268	Lockheed Martin Corporation
NJ	Carteret	40°34'44.70"N	74°13'0.50"W	83	E950361	SESMOD2000080801394	All Mobile Video, Inc.
NJ	Carteret	40°34'45.40"N	74°12'59.50"W	83	E950372	SESMOD2000080801390	All Mobile Video, Inc.
NJ	Franklin	41°7'4.00"N	74°34'33.00"W	n/s	E6777	SESLIC1999031200365	Sprint Communications Company, L.P.
NJ	Franklin	41°7'4.00"N	74°34'33.00"W	n/s	KA231	SESRWL1997062300835	US Sprint Communications Company L.P.
NY	Hauppauge	40°49'15.40"N	73°15'48.40"W	83	E950436	SESMOD2002030700321	Reuters America, Inc.
NY	Hauppauge	40°48'53.60"N	73°14'18.40"W	83	E970361	SESMOD2000112202201	Globecomm Systems, Inc.
OR	Moores Valley	45°20'32.40"N	123°17'19.40"W	83	KA365	SESLIC2003100201362	Neptune Pacific License Corporation
PA	Catawissa	40°53'39.00"N	76°26'21.00"W	27	E980493	SESMOD2000112902217	AT&T Corp
PA	Hawley	41°27'51.00"N	75°7'47.90"W	27	E950209	SESMOD1996073100731	Loral Spacecom Corporation
PA	Roaring Creek	40°53'35.90"N	76°26'22.60"W	n/s	KA444	SESRWL2002041800608	AT&T Corp.
PA	Roaring Creek	40°53'37.50"N	76°26'21.80"W	27	WA33	SESRWL2004032300452	AT&T Corp.
PR	Carolina	18°26'0.00"N	65°59'35.00"W	27	KA377	SESRWL2003071000942	Americom Government Services, Inc.
PR	Humacao	18°9'5.00"N	65°47'20.00"W	n/s	E872647	SESRWL2000091201765	Telecommunicaciones Ultramarinas de Puerto Rico
PR	San Juan	18°26'47.00"N	66°3'58.00"W	27	KA466	SESLIC1995030600004	Telecommunicaciones Ultramarinas de Puerto Rico
TN	Nashville	36°14'5.70"N	86°45'21.40"W	n/s	E960050	SESLIC1995101100315	Northstar Studios, Inc.

State	City	Latitude	Longitude	NAD*	Call Sign	Filenumber	Licensee
TN	Nashville	36°14'5.70"N	86°45'19.40"W	n/s	E960073	SESLIC1995101700295	Northstar Studios, Inc.
TN	Nashville	36°14'6.20"N	86°45'20.40"W	n/s	E970010	SESLIC1996100800361	Northstar Studios, Inc.
TX	Desoto	32°37'48.00"N	96°50'32.00"W	n/s	KA306	SESRWL2002030300266	Megastar Inc
VA	Alexandria	38°47'38.00"N	77°9'46.00"W	27	E970267	SESMOD2004070200978	SES Americom, Inc.
VA	Alexandria	38°47'36.00"N	77°9'59.00"W	27	KA81	SESMOD1998071701970	SES Americom, Inc.
VA	Bristow	38°47'1.60"N	77°34'24.30"W	83	E000152	SESMOD2004020900202	New Skies Networks, Inc.
VA	Bristow	38°47'2.40"N	77°34'21.90"W	83	E000696	SESMOD2003102801506	New Skies Networks, Inc.
VA	Quicksburg	38°43'45.40"N	78°39'25.10"W	83	E000589	SESLIC2000082401509	MCI WORLDCOM Network Services, Inc.
VA	Quicksburg	38°43'45.40"N	78°39'25.10"W	83	E010140	SESLIC2000113002478	MCI WORLDCOM Network Services, Inc.
VA	Quicksburg	38°43'45.40"N	78°39'24.20"W	83	E990175	SESMOD2000113002226	MCI WORLDCOM Network Services, Inc.
VA	Reston	38°57'0.00"N	77°22'40.00"W	n/s	E950406	SESLIC1995062900762	Sprint Communications Company, L.P.
WA	Brewster	48°8'51.00"N	119°41'29.00"W	n/s	E960222	SESLIC1996022101766	SES Americom, Inc.
WA	Brewster	48°8'49.00"N	119°41'28.00"W	27	KA20	SESRWL2002110601960	SES Americom, Inc.
WA	Brewster	48°8'51.00"N	119°41'29.00"W	n/s	KA294	SESRWL2003072201015	SES Americom, Inc.
WA	Yacolt	45°51'46.40"N	122°23'44.30"W	83	KA221	SESMOD1999082001537	MCI WORLDCOM Network Services, Inc.
WA	Yacolt	45°51'45.50"N	122°23'43.80"W	83	KA323	SESMOD1999082001536	MCI WORLDCOM Network Services, Inc.
WV	Albright	39°34'7.00"N	79°34'45.00"W	27	KA413	SESRWL2004060800805	AT&T Corp.
WV	Etam	39°16'50.00"N	79°44'13.00"W	n/s	KA378	SESRWL2001060801039	AT&T Corp.
WV	Etam	39°16'48.00"N	79°44'14.00"W	27	WA21	SESRWL2001060801038	AT&T Corp.
WV	Rowlesburg	39°16'52.10"N	79°44'10.70"W	n/s	KA351	SESRWL2002092301654	AT&T Corp
WY	Cheyenne	41°7'56.00"N	104°44'10.50"W	27	E950253	SESMOD2000050500706	Echostar North America Corporation
WY	Cheyenne	41°7'55.70"N	104°44'11.50"W	27	E980118	SESMOD2001111402151	Echostar North America Corporation

APPENDIX F: Protection Zones For Grandfathered FSS And Federal Government Stations